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FINAL REPORT

OPTICAL EQUIPMENT TEST KIT

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December 1971

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ABSTRACT

The development program for an optical equipment test kit is discussed in terms of: (1) The equipment provided in the test kit; (2) the packaging requirements of the test kit, and (3) the methods and results of a preliminary acceptance test program performed by the contractor on the test kit components. In addition, recommendations are given concerning the future development of optical equipment test kits.

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SECTION I

INTRODUCTION

The purpose of this program was to develop a prototype optical equipment test kit compatible with field-testing requirements of image-viewing systems which include: Microstereoscopes, stereomicroscopes, light tables, projection viewers, and simple magnifiers. The deliverable items included both the optical equipment test kit and a manual describing, in detail, the testing methods required for the proper utilization of the components of the test kit.

This report summarizes the important subtasks that were performed in support of this test kit development program, including recommendations for future consideration in terms of both the testing procedures and the test kit components.

The first main section of this report describes the optical equipment test kit, including both the components and their packaging requirements. The second main section reviews the results of a component testing program performed by the contractor for the purpose of preliminary component acceptance. The final section summarizes important information and results found within the time period of this development program.

SECTION II

TEST KIT DESCRIPTION

A program monitor — responsible for the field testing of prototype optical equipment such as microstereoscopes, stereomicroscopes, light tables, projection viewers, and simple magnifiers — requires the capability to evaluate such equipment in a way that will detect and in some instances quantify major discrepancies between actual performance and performance requirements. These may include determination of field-of-view, magnification, resolving power, field distortion, astigmatism, parfocality of stereoscopic instruments and zoom systems, phoria, image runoff, interpupillary distance, eye relief, vignetting, field curvature, and illumination level and variability.

A. COMPONENTS

In order to implement the evaluation capability, the optical equipment test kit has been developed. The components within this kit, as listed in Table I, provide accurate measurement capability for all optical and mechanical tests specified in the manual of Testing Procedures for Optical Equipment Test Kits*. Note that each component within the list has been assigned a test kit component (TKC) number to simplify referencing procedures within this report and the manual. In addition, reference is given to the supplier, basic materials, precision, and accuracy of the component. The precision and accuracy values listed in Table I are based on the component manufacturer's specifications.

B. PACKAGING

The packaging requirements of the optical equipment test kit have been fulfilled utilizing three basic types of packages.

1. Case: A Skydyne A-B-S (Acrylonitrile-Butadiene-Styrene) Thermoformed Case has been provided. This particular case is the smallest standard Skydyne case that can be used to package all of the components in the test kit. The case is light weight, corrosion resistant, has good insulating properties, high impact strength, and a high energy-absorption capability.

*Contractor's manual DM-71-17, November 1971.

TABLE I. OPTICAL TEST KIT COMPONENT LIST

No.	Item	Description	Supplier	Material	Precision	Accuracy
1	Diopter Telescope	Range: +4 to -5 diopters Mag.: 3X Length: 3-1/16 in. (closed) Length: 3-1/2 in. (open) Diameter: 1-3/8 in. Field-of-View: 12°40'	Krueff & Esser Company	Glass	±0.2 diopter	±0.1 diopter
2	10X Eyepiece	Widefield Eyepiece	Daussch & Lomb	Glass with Chrome Housing	N/A	
3	Coaxial Scale Reticle	Diameter: 21 mm Outer ring: 10 mm Scales = 100 divisions	Edmund Scientific	Glass	0.1 mm	
4	Concentric Circle Reticle	Diameter: 21 mm Concentric Circles 0.5 mm to 12 mm	Edmund Scientific	Glass	0.5 mm	
5	Microscope Grid Reticle	Diameter: 21 mm	Faling Corp.	Glass	0.1 mm	
6	Microscope Grid Reticle	Diameter: 21 mm	Edmund Scientific	Glass	0.5 mm squares	
7	Microscope Grid	Dimensions: 50 x 50 mm	Max Levy	Crown Polyester Film Base	1.0 mm	±0.01 mm
8	Large Field Grids (2)	Dimensions: 4 in. x 5 in. 5 in. x 9 in.	Max Levy	Crown Polyester Film Base	0.1 in. 0.2 in.	±0.005 in.
9	Forced Vibration Target	Dimensions: 1 in. x 2 in. Target Length: 0.25 in.	Faling Corp.	Glass	0.001 in.	
10	High-Resolution Target	High-Contrast 15-500 lines/mm Dimensions: 2 in. x 2 in.	Dek Corp.	High-Resolution Photographic Plate	2.5	

TABLE 1. OPTICAL TEST KIT COMPONENT LIST (cont'd.)

No.	Item	Description	Supplier	Material	Precision	Accuracy
11	High-Resolution Target	Low-Contrast 16-900 lines/mm Dimensions: 2 in. x 2 in.	Bek Corp.	High-Resolution Photographic Plate	$\pm 1/6$	
12	Alignment and Orthogonality Target	Dimensions: 4 1/2 in. x 2 1/2 in. x 1 1/4 in.	Contractor	High-Resolution Photographic Plate	Length: ± 0.002 in.	
13	Transparent Scale	Scale Length: 5 mm	Contractor	High-Resolution Photographic Plate	0.01 mm	
14	Translucent Scale	Length: 10 cm	Edmund Scientific	Glass Slide w/ Plastic Tape	2.0 mm	
15	Stage Micrometer	Dimensions: 25 x 15 mm Scales: 2 mm length divided into 200 units	American Optical	Glass	0.01 mm	
16	Metal Scale	Length: 50 cm Width: 25.6 mm	L. S. Starrett Co.	Satin-Chrome Spring-Tempered	1/2 mm, 1 mm 1/32 in., 1/64 in.	
17	Machinist Scale	Length: 6 in.	L. S. Starrett Co.	Satin-Chrome Spring-Tempered	1/2 mm, 1 mm 1/64 in., 1/32 in.	
18	Tape Measure	Length: 6 ft. Retractable	Sears Craftsman	Metallic	1/16 in.	
19	Calipers	Vernier Calipers Length: 8 in. Capacity: 0-5 1/2 in.	Sears Craftsman	Stainless steel	1/20 mm 1/1000 in.	
20	Dial Indicator and Stand	Dial Indicator Range: 0-2 in.	L. S. Starrett Co.	Steel	0.001 in.	

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TABLE I. OPTICAL TEST KIT COMPONENT LIST

No.	Item	Description	Supplier	Material	Precision	Accuracy
1	Diopter Telescope	Range: +1 to -5 diopters Mag. : 2X Length: 3-1/16 in. (closed) Length: 3-1/2 in. (open) Diameter: 1-3/8 in. Field-of-View: 12°40'	Kueffel & Esser Company	Glass	0.2 diopter	0.1 diopter
2	10X Eyepiece	Widfield Eyepiece	Bausch & Lomb	Glass with Chrome Housing	N/A	
3	Crosshairs Scale Reticle	Diameter: 21 mm Orthogonal: 10 mm Scales: 100 divisions	Edmund Scientific	Glass	0.1 mm	
4	Concentric Circle Reticle	Diameter: 21 mm Concentric Circles 0.5 mm to 12 mm	Edmund Scientific	Glass	0.5 mm	
5	Microscope Grid Reticle	Diameter: 21 mm	Falling Corp.	Glass	0.1 mm	
6	Microscope Grid Reticle	Diameter: 21 mm	Edmund Scientific	Glass	0.5 mm squares	
7	Microscope Grid	Dimensions: 50 x 50 mm	Max Levy	Cronar Polyester Film Base	1.0 mm	0.01 mm
8	Large Field Grids (2)	Dimensions: 4 in. x 5 in. 9 in. x 9 in.	Max Levy	Cronar Polyester Film Base	0.1 in. 0.2 in.	+0.0005 in.
9	Percept Vision Target	Dimensions: 1 in. x 2 in. Target Length: 0.25 in.	Falling Corp.	Glass	0.001 in.	
10	High-Resolution Target	High-Contrast 10-900 lines/mm Dimensions: 2 in. x 2 in.	Ittek Corp.	High-Resolution Holographic Plate	1.0 2.0	

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TABLE 1. OPTICAL TEST KIT COMPONENT LIST (cont'd.)

No.	Item	Description	Supplier	Material	Precision	Accuracy
11	High-Resolution Target	Low-Contrast 16-800 lines/mm Dimensions: 2 in. x 2 in.	Itok Corp.	High-Resolution Photographic Plate	$\pm .6$	
12	Astigmatism and Orthogonality Target	Dimensions: 4 in. x 5 in. x 1/4 in.	Contractor	High-Resolution Photographic Plate	Length: ± 0.0002 in.	
13	Transparent Scale	Scale Length: 5 mm	Contractor	High-Resolution Photographic Plate	0.01 mm	
14	Translucent Scale	Length: 10 cm	Edmund Scientific	Glass Slide w/ Plastic Tape	2.0 mm	
15	Stage Micrometer	Dimensions: 25 x 75 mm Scale: 2 mm length divided into 200 units	American Optical	Glass	0.01 mm	
16	Metal Scale	Length: 50 cm Width: 25.6 mm	L. S. Starrett Co.	Stainless-Steel Spring-Tempered	1/2 mm, 1 mm 1/32 in., 1/16 in.	
17	Machinist Scale	Length: 6 in.	L. S. Starrett Co.	Stainless-Steel Spring-Tempered	1/2 mm, 1 mm 1/16 in., 1/32 in.	
18	Tape Measure	Length: 6 ft. Retractable	Sears Craftsman	Metallic	1/16 in.	
19	Calipers	Vernier Calipers Length: 8 in. Capacity: 5-5.16 in.	Sears Craftsman	Stainless Steel	1/20 mm 1/1000 in.	
20	Dial Indicator and Stand	Dial Indicator Range: 0.2 in.	L. S. Starrett Co.	Steel	0.001 in.	

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TABLE 1. OPTICAL TEST KIT COMPONENT LIST (cont'd.)

No.	Item	Description	Supplier	Material	Precision	Accuracy
21	Surface Thermometer	Diameter: 2 in. Thick: 9/16 in. Range: 0-500 F.	Arthur Thomas Co.	Metallic Back Glass Face	2°F	
22	Tension Tester	12 lb. Spring Scale	Chatillon Scales	Metallic	2 oz.	
23	Hole Punch	1/4 in. Hole	S&V Office Equipment	Steel	N/A	
24	Stop Watch	Time Capacity: 30 min. Start, Stop, Reset Button	Edmund Scientific	Chrome-Plated Case	1/10 sec	
25	Light Meter	Exposure Meter Photoelectric Cell Range: 0.2 to 6400 f.c.	Weston Instruments			
26	Illuminator	Daylight Fluorescent Lamp and Cord	American Optical	Metallic Base Glass Tubes		
27	Variable Angle Reflector	Magnetic Mount Front-Surface Plane Mirror Diameter: 1-5/16 in.	Edmund Scientific	Metallic Base Glass Face	N/A	
28	Polarizing Filter	Dimensions: 5 in. x 5 in. x 0.01 in.	Edmund Scientific	Plastic Acetate	Crossed Transmission Mettman 2T	
29	Spectral Filters	Dimensions: 3 in. x 3 in. Red, Green, and Blue Filters	Eastman Kodak	Gelatin Film	N/A	
30	Neutral Density Filters	Dimensions: 3 in. x 3 in. Density: 0.5, 1.0, 2.0	Eastman Kodak	Gelatin Film	± 0.03	
31	Step Tablet	21-Step Tablet Density Increment: 0.15 Dimensions: 1 in. x 5-1/2 in.	Eastman Kodak	Film	± 0.03	

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TABLE 1. OPTICAL TEST KIT COMPONENT LIST (cont'd.)

No.	Item	Description	Supplier	Material	Precision	Accuracy
32	Lens Brush	1 in. Flat Brush	Eastman Kodak	Camel Hair	N/A	
33	Hand Magnifier	Diameter: 3 in. Magnification: 2X	Edmund Scientific	Glass	N/A	
34	Flashlight	Small Wt. 3 oz.	Newark Electronics	Chrome Finish	N/A	
35	Case	A-B-S Case Dimensions: 19.38 in. x 14.14 in. x 14.19 in.	Skydive	Acrylonitrile- Butadiene- Styrene	N/A	

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2. Package Inserts: Ethafoam expanded polyethylene is provided as a package insert material. It is light weight, durable, flexible, resistant to chemical attack by preservatives or oils, and seals out environmental conditions such as air, water, and dust. The insert provided consists of three basic levels for component storage. The pockets were designed to match the contours of their respective components, and the overall insert contour was designed for the case previously described.

3. Component Packages: Most of the components provided in the test kit are enclosed in individual packages within the case insert. These individual packages consist of plastic cases supplied by the component manufacturers, plastic cases provided by the contractor, and foamvelopes made of expanded foam plastic purchased by the contractor. The selection of the component packages was made to provide added protection for the components most susceptible to physical damage. For example, all glass targets, microscope reticles, the diopter telescope, and the widefield eyepiece were provided with plastic cases.

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SECTION III

COMPONENT ACCEPTANCE TESTING

The component acceptance testing procedures performed by the contractor were designed as preliminary tests of component precision, accuracy, and feasibility. Additional acceptance testing is anticipated within the sponsor's testing facilities to determine the overall value of each of the components in the test kit in terms of its ability to meet the sponsor's test requirements for image-viewing systems and related equipment. Final evaluation of the individual requirement for each of the components can then be based on the results of these two testing programs.

The acceptance testing procedures performed by the contractor were divided into three classes of inspection, as follows.

1. Class I - Precision Testing: The equipment and procedures utilized in these tests produce very high accuracy and precision. They are comparable, and in some cases traceable, to those utilized by the National Bureau of Standards.
2. Class II - Comparable Testing: These tests are performed using test kit components evaluated in Class I as the standard of comparison.
3. Class III - Visual Inspection: Visual inspection is utilized to determine if the test kit components meet the subjective standards provided by the component manufacturer.

Each of the components tested will be individually discussed within its respective classification.

A. CLASS I INSPECTION

An outline of the methods and results of the Class I inspection procedures is given in Table II. Each of the component tests is described in the following discussion, using the TKC numbers as the component reference.

1. TKC 1 - Diopter Telescope: The precision and accuracy of the diopter telescope are specified by the manufacturer in terms of diopters rather than in terms of focusing distance and depth of focus along the instrument's optical axis. To calculate

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TABLE II. CLASS I INSPECTION OUTLINE

Item	Component Description	Method of Inspection	Precision	Accuracy
1	Diopter Telescope	Optical Ball	0.2 diopters	
2	10X Eyepiece	Nodal Slide Optical Bench		± 0.1 power
3	Crossline Reticle	Unitron Microscope	0.1 mm	
4	Concentric Circle Reticle	Unitron Microscope	0.5 mm	
5	Microscope Grid Reticle	Unitron Microscope	0.1 mm squares	
6	Microscope Grid Reticle	Unitron Microscope	0.5 mm squares	
7	Microscope Grid (50 x 50 mm)	Mann Comparator	1.0 mm squares	
9	Foeppl Vibration Target	Unitron Microscope	0.001 in.	
10	Resolution Target (High-Contrast)	Microdensitometer		Approximately 20:1 contrast ratio
11	Resolution Target (Low-Contrast)	Microdensitometer		0.3 density difference ± 0.05 at 64 lines/mm
12	Astigmatism and Orthogonality Target	Mann Comparator	± 0.0002 in. or ± 5 micrometers	
13	Transparent Scale	Microdensitometer	0.01 mm	
15	Stage Micrometer	Microdensitometer	0.01 mm	
16	Metal Scale (50 cm)	Hoke Gage Blocks and Surface Plate	0.5 and 1 mm 1/64 and 1/32 in.	
19	Calipers	Hoke Gage Blocks	1/20 mm 0.001 in.	
20	Dial Indicator	Hoke Gage Blocks and Surface Plate	0.001 in.	
24	Stop Watch	NBS Pacific Station WWV	1/10 sec	
25	Light Meter	Calibrated Source		
31	Step Tablet	Macheth TD-102 Densitometer	± 0.03	

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these values, more information must be known concerning the optical elements and their physical positions within the diopter telescope; a theoretical analysis must then be performed. Since such an analysis is beyond the scope of this program, the translation to focusing distance (based upon manufacturer's specifications) is not presently available. However, it is within the scope of this program to evaluate the performance of the diopter telescope as it might be used under future operational conditions, such as in the measurement of focus position along the optical axis of an image-viewing system like a microstereoscope.

This evaluation (including measurements of the focusing distance, field-of-view, depth of focus, and resolution as functions of the diopter setting of the diopter telescope) has been performed. All measurements were made on a 3-meter optical rail with the diopter setting used as the specified variable for each measurement. The measurement data are listed in Table III.

A plot of the focusing distance versus the diopter setting, as shown in Figure 1, indicates that a nonlinear relationship exists between these variables. This was anticipated and is the basis for the conversion formula utilized in the manual for optical testing procedures. Note that the focus position distance will increase very rapidly as the diopter setting values become more positive. This seems to indicate that the useful range of the diopter telescope, for measurement of focal plane positions within a microstereoscope system, will probably be within the -5.0 to -3.0 diopter range. An absolute range cannot be established at this time because the magnification and depth of focus of the microstereoscope system will both be important factors when using the diopter telescope as a focus-position-measuring device. In addition, the depth of focus of the diopter telescope cannot be greater, less sensitive, than the microstereoscope system being tested. Although the depth of focus data given in Table III indicate 0.3 mm as the most sensitive value, it is again important to realize that the magnification of a stereomicroscope system will effectively reduce this depth of focus. The value to which this depth of focus will be reduced is left for future investigation and will be further discussed in the recommendations section of this report.

2. TKC 2 - 10X Widefield Eyepiece: Manufacturers' specifications for eyepieces have been found to be quite unclear in that an absolute tolerance is not generally estab-

TABLE III. DIOPTR TELESCOPE TEST DATA*

<u>Diopter Setting</u>	<u>Focus Distance (mm)</u>	<u>Field of View (mm)</u>	<u>Depth of Focus</u>	<u>Resolution Observed (lines/mm)</u>	<u>Repeatability Check</u>
- 5.0	211.6	37	0.3	22.6	
- 4.8	223.3				
- 4.6	232.7	42			
- 4.4	245.2	42			
- 4.2	259.6				
- 4.0	273.1	51	4.2	20.1	
- 3.8	291.2				
- 3.6	309.5	61			
- 3.4	335.4	61			
- 3.2	361.1				
- 3.0	386.5	77	6.5	14.3	
- 2.5	472.5	91			
- 2.0	614.9			8.0	614.9 610.0 613.6 613.0 612.0
- 1.0	1474.7	330		2.8	
- 0.95					
- 0.90	2400.0	546	≈ 100 mm		
0					
+ 1.0					

(OPTICAL BENCH LIMITATION)

*These tests were performed independently of any viewing instrument other than the diopter telescope. The data will change, dependent upon the optical parameters of any viewing system that is used in conjunction with the diopter telescope.

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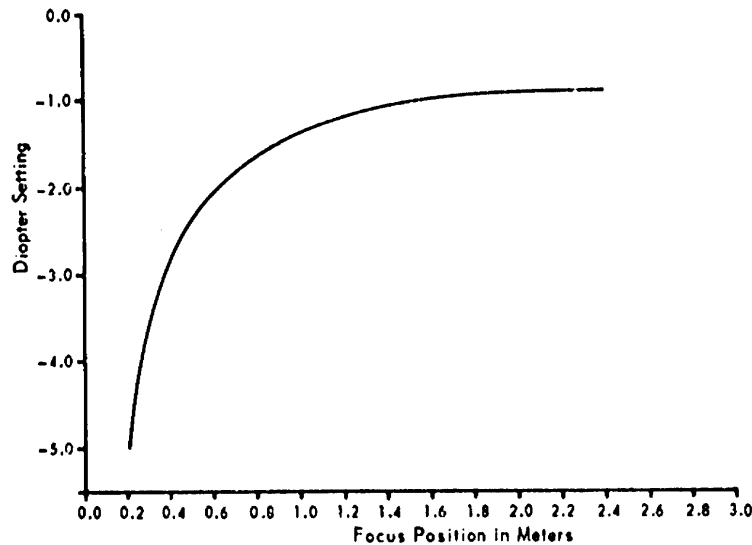


Figure 1. Focus Position Versus Diopter Setting

lished and accepted through the industry. Therefore, rather than testing against the manufacturer's specifications established for this 10X widefield eyepiece, the contractor has performed a detailed measure of the magnification across a 9.5-millimeter field-of-view. All measurements were performed on a lens bench consisting of a nodal slide arrangement and precision lead screws. The lens bench was built especially for the contractor for the purpose of testing microscope objectives and lenses. The accuracy of all measurements is ± 1 micrometer.

The optical setup utilized to measure the magnification is shown in Figure 2. A high-resolution target is imaged by the 10X widefield eyepiece and viewed through a microscope setup consisting of a 10X Zeiss objective and two 16X Zeiss eyepieces. Both the resolution target holder and the Zeiss viewing mount were designed to provide X and Y movement, i.e., perpendicular to the optical axis. The presence of a cross-line reticle in the focal plane of one of the Zeiss eyepieces allows for comparison of a movement in the target to the movement of the spatial image of the target. The relationship between these distances determines the magnification across the field-of-view of the 10X widefield eyepiece.

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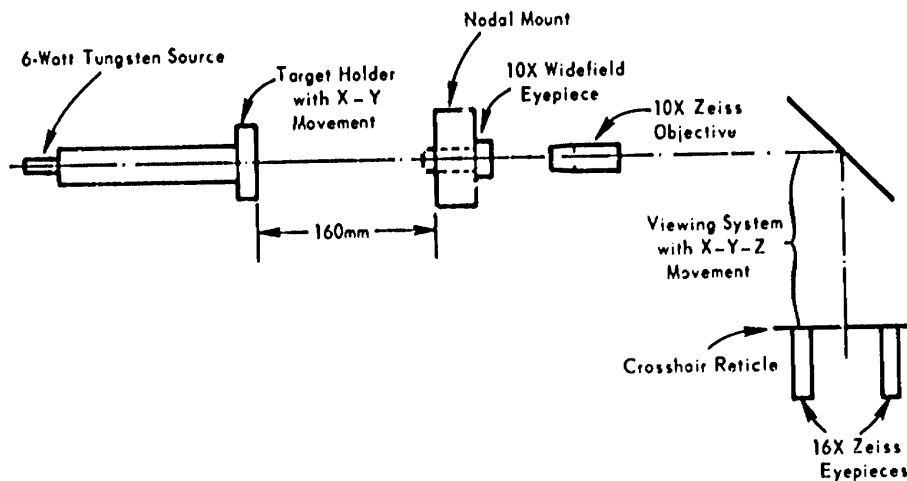


Figure 2. Lens Bench Arrangement for Measuring Eyepiece Magnification

A plot of the magnification values measured versus the distance off-axis is given in Figure 3. The maximum error of magnification is observed to be 0.15X across a 19.0-millimeter field-of-view.

3. TKC 3 - Crossline Reticle: The crossline reticle has two scales, each 10 millimeters in length and divided into 100 divisions to provide a precision of 0.1 millimeter. Measurements to determine the location of the divisions were performed using a Unltron Research Microscope with a measurement accuracy of ± 0.0001 inch (± 2.54 micrometers).

The results of these measurements are given in Table IV. The maximum horizontal scale error is 10 micrometers at the 10-millimeter division. The maximum vertical scale error is 9 micrometers at the 6- and 10-millimeter divisions. All measured errors are negligible compared to the manufacturer's 0.1-millimeter scale precision requirement.

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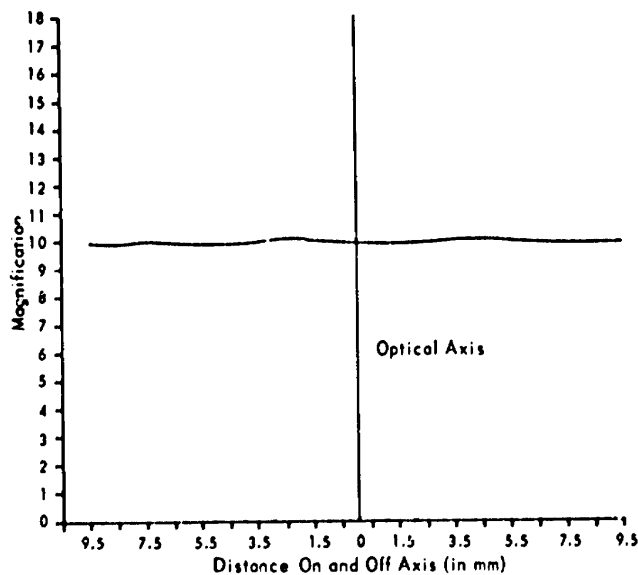


Figure 3. Magnification Versus Distance from Optical Axis

TABLE IV. CROSSLINE RETICLE TEST DATA

<u>Horizontal Scale (mm)</u>	<u>Measured Horizontal Scale (mm)</u>	<u>Vertical Scale (mm)</u>	<u>Measured Vertical Scale (mm)</u>
0.0	0.000	0.0	0.000
1.0	0.998	1.0	1.000
2.0	1.996	2.0	2.005
3.0	2.995	3.0	3.003
4.0	3.995	4.0	4.003
5.0	5.000	5.0	5.002
6.0	6.001	6.0	6.009
7.0	7.000	7.0	7.007
8.0	8.006	8.0	8.008
9.0	9.008	9.0	9.008
10.0	10.010	10.0	10.009

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4. TKC 4 — Concentric Circle Reticle: This reticle consists of concentric circles ranging in diameter from 0.5 to 12.0 millimeters with a precision of 0.5 millimeter. Measurements to determine the accuracy of the circles were made using a Unitron Research Microscope with a measurement accuracy of ± 0.0001 inch (± 2.54 micrometers).

The results of these measurements are given in Table V. The maximum measured error is 12 micrometers for the 9.5- and 10.5-millimeter diameter circles. All errors are negligible compared to the manufacturer's 0.5-millimeter precision.

5. TKC 5 — Microscope Grid Reticle: This reticle consists of a 1-millimeter square grid divided into increments of 0.1 millimeter. Measurements were taken of all major divisions to determine the grid accuracy using a Unitron Research Microscope with a measurement accuracy of ± 0.001 inch (± 2.54 micrometers).

TABLE V. CONCENTRIC CIRCLE RETICLE MEASUREMENT DATA

<u>Circle Diameter (mm)</u>	<u>Measured Diameter (mm)</u>
12.0	12.003
11.5	11.492
11.0	10.997
10.5	10.488
10.0	9.989
9.5	9.488
9.0	8.992
8.5	8.493
8.0	7.995
7.5	7.494
7.0	6.989
6.5	6.490
6.0	5.989
5.5	5.502
5.0	5.002
4.5	4.499
4.0	4.000
3.5	3.499
3.0	2.998
2.5	2.494
2.0	2.002
1.5	1.499
1.0	0.996
0.5	0.502

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The results of these measurements are given in Table VI. The maximum error measured in the numerical direction is estimated to be less than 2.54 micrometers. The maximum error in the lettered direction is estimated to be 3 micrometers. The measured line width is approximately 4 micrometers. All errors are considered negligible compared to the 0.1-millimeter precision requirement of the grid.

6. TKC 6 — Microscope Grid Reticle: This reticle contains a grid across the entire 21-millimeter diameter of the reticle. The grid precision is specified by the manufacturer as 0.5 millimeter per increment. Measurements were performed over randomly selected areas of the grid to determine its accuracy using a Unifon Research Microscope with a measurement accuracy of ± 0.0001 inch (± 2.54 micrometers).

The results of these measurements indicated that the maximum line-spacing error in one direction was 4 micrometers in 20 millimeters. In the direction perpendicular to this, the maximum line-spacing error was found to be less than 2.54 micrometers in 20 millimeters. The line width was found to be approximately 19 micrometers. All errors are considered negligible compared to the 0.5-millimeter precision requirement of the grid.

7. TKC 7 — Microscope Grid: This is a square grid target with a length of 50 millimeters on each side divided into 2-millimeter squares. The base material is Cronar polyester and the target manufacturer specifies a 0.01-millimeter dimensional accuracy. Measurements were performed over randomly selected areas of the grid to determine its accuracy using a David W. Mann Comparator with a measurement accuracy of ± 1 micrometer.

The maximum measured error was found to be 15 micrometers in 50 millimeters. The line widths of the centimeter divisions were approximately 150 micrometers and the line widths of the millimeter divisions were approximately 80 micrometers. Note that the measured accuracy of 15 micrometers exceeds the 10 micrometers stated by the manufacturer. If the target were to be used for high-precision quantitative measurements, this 5-micrometer difference would probably be significant. However, the target is used only in subjective tests and its measured accuracy is still more than 60 times greater than its smallest grid size. Therefore, the measurement error is considered negligible compared to the manufacturer's grid precision.

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TABLE VI. MEASUREMENT DATA FOR ASTIGMATISM AND ORTHOGONALITY TARGET

Ideal Positions		Actual Target Positions		Error	
X (mm)	Y (mm)	X (mm)	Y (mm)	X (mm)	Y (mm)
0	0	0	0	0	0
0.950	0	0.951	0	+ 0.001	0
2.540	0	2.539	0	- 0.001	0
6.350	0	6.350	0	+ 0.005	0
10.795	0	10.795	0	0.000	0
19.050	0	19.048	0	- 0.002	0
44.450	0	44.449	0	- 0.001	0
- 0.950	0	- 0.954	0	+ 0.004	0
- 2.540	0	- 2.542	0	+ 0.002	0
- 6.350	0	- 6.352	0	+ 0.002	0
- 10.795	0	- 10.795	0	0.000	0
- 19.050	0	- 19.052	0	+ 0.002	0
- 44.450	0	- 44.451	0	+ 0.001	
0	0.950	0	0.952	0	+ 0.002
0	2.540	0	2.541	0	+ 0.001
0	6.350	0	6.349	0	- 0.001
0	10.795	0	10.795	0	0.000
0	19.050	0	19.051	0	+ 0.001
0	44.450	0	44.450	0	0.000
0	- 0.950	0	- 0.952	0	+ 0.002
0	- 2.540	0	- 2.540	0	0.000
0	- 6.350	0	- 6.349	0	- 0.001
0	- 10.795	0	- 10.797	0	+ 0.002
0	- 19.050	0	19.051	0	+ 0.001
0	- 44.450	0	44.451	0	+ 0.001
44.450	44.450	44.448	44.451	- 0.002	+ 0.001
- 44.450	44.450	- 44.452	44.451	+ 0.002	+ 0.001
44.450	- 44.450	44.449	- 44.452	- 0.001	- 0.002
- 44.450	- 44.450	- 44.451	- 44.451	+ 0.001	- 0.001

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8. TKC 9 - Foeppl Vibration Target: This target contains 20 pairs of 0.001-inch dots converging on a single dot. The distance between each pair of dots increases at a rate of 0.001 inch to a maximum of 0.02 inch in the last pair. All pairs of dots are equi-spaced over 0.25 inch. Measurements were performed to determine the accuracy of the dot separation.

9. TKC 10 - High-Resolution, High-Contrast Target: A high-resolution, high-contrast three-bar target has been included in the test kit. It has a resolution range from 16 to 912 line pairs per millimeter and includes resolution increments specified by multiple steps of $2^{1/6}$ within each of its 6 groups. In addition, all bars are specified as having a 5:1 aspect ratio (length-to-width ratio). The selection of the target included in this kit was based upon mutual agreement between the contractor and the sponsor's technical representatives.

Two measurement procedures were performed for the evaluation of the resolution target. The first procedure was a subjective evaluation of the resolution target using the Unltron Research Microscope at various magnifications up to 600X. The second procedure was a quantitative evaluation of the resolution target using a microdensitometer.

The subjective tests indicated that each resolution element could be identified up to and including group 9 element 6, which corresponds to 912 line pairs per millimeter. In addition, the element bars were considered to be recognizable as rectangular bars throughout the resolution range.

The objective test results are shown in Figure 4. The entire target was scanned using a submicrometer spot size to minimize degradation of the density response due to the scanning aperture. It is readily apparent that the target contrast is not uniform across all resolution elements, where the contrast, C , is defined in terms of the target density difference, ΔD , by

$$C = \log^{-1} \Delta D$$

The definition of a high-contrast target, as given in Mil-Std-150A, specifies a density difference exceeding 2.00 between light and black areas. This criterion is

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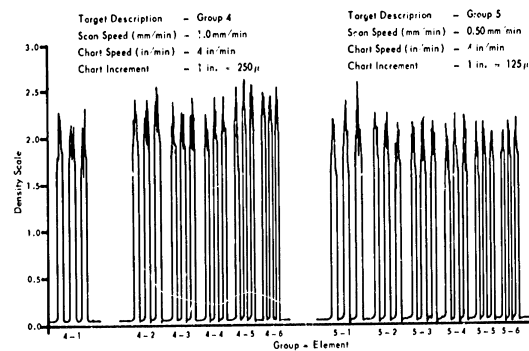


Figure 4. Microdensitometer Scan of High-Resolution, High-Contrast Target

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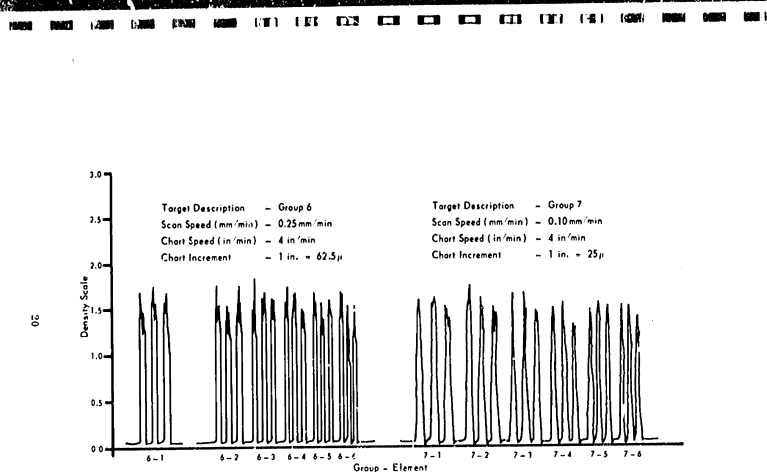


Figure 4. Microdensitometer Scan of High-Resolution, High-Contrast Target (cont'd.)

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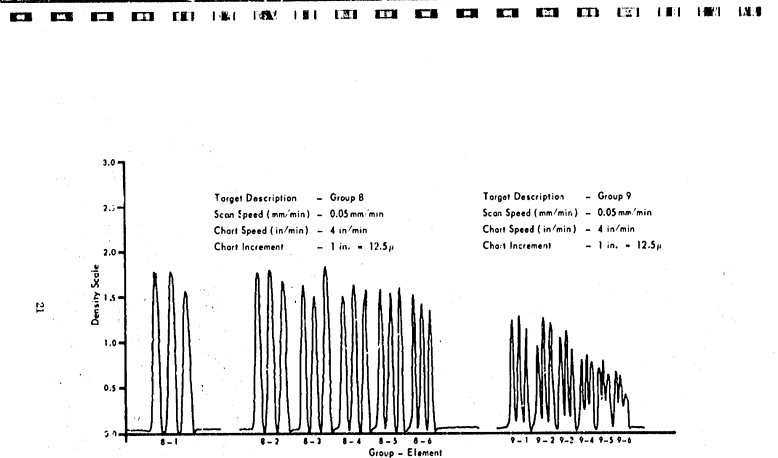


Figure 4. Microdensitometer Scan of High-Resolution, High-Contrast Target (cont'd.)

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met by groups 4 and 5 of the target (16 through 57 line pairs per millimeter) and corresponds to a contrast ratio of 100:1.

All commercially available* high-resolution, high-contrast targets deteriorate rapidly in terms of density difference or contrast for the higher resolution elements. This deterioration is a result of the expense and technology required to maintain a high and fairly uniform contrast. Therefore, most manufacturers have established specifications which meet the Mil-Stds for lower resolution elements and are also applicable to the higher resolution elements.

The target included in this test kit is specified by the manufacturer as having a contrast of approximately 20:1 or greater, which is their standard high-contrast, high-resolution target specification. This contrast ratio corresponds to a density difference, ΔD , of approximately 1.3, which is applicable to resolution groups 4 through 8 as shown in Figure 4. Further increases in the contrast of group 9 would probably require a special development program by the target manufacturer at additional cost.

Based upon the test results, the target is deemed acceptable by the contractor since it meets the manufacturer's specifications. However, recommendations concerning the requirements of high-resolution targets are given in Section IV of this report.

10. TKC 11 - High-Resolution, Low-Contrast Target: The target format and specifications are identical to TKC-10, with the exception that this is a low-contrast target. The selection of this target was based upon mutual agreement between the contractor and the sponsor's technical representatives. Tests performed by the contractor are identical to those performed for TKC-10.

The subjective tests indicated that all resolution elements could be identified as three-bar groupings including element 9-6, 912 line pairs per millimeter. The target is considered to be subjectively acceptable.

The objective test results are shown in Figure 5. The manufacturer's specifications for the low-contrast target require a 0.3 density difference ± 0.05 as measured at the 64-line-per-millimeter element with a microdensitometer. The results of the den-

*Assuming targets readily available as off-the-shelf items at a cost not exceeding \$500.00.

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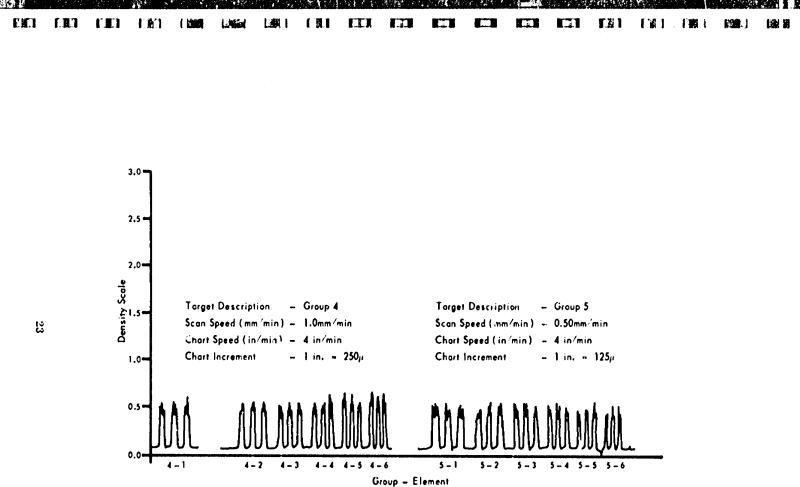


Figure 5. Microdensitometer Scan of High-Resolution, Low-Contrast Target

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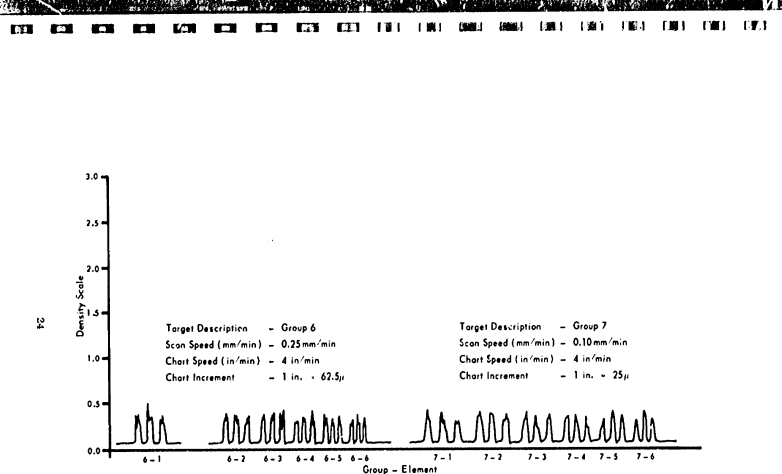


Figure 5. Microdensitometer Scan of High-Resolution, Low-Contrast Target (cont'd.)

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

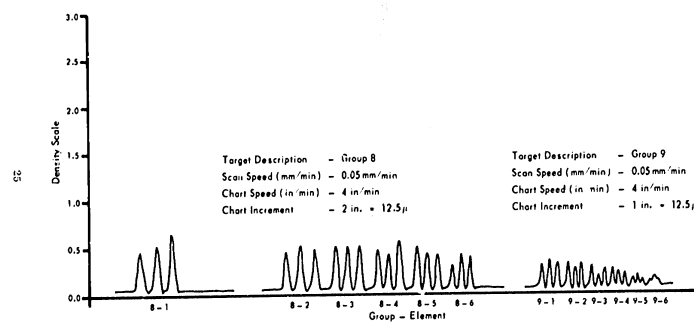


Figure 5. Microdensitometer Scan of High-Resolution, Low-Contrast Target (cont'd.)

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sity profile given in Figure 5 indicate that this requirement has been fulfilled and the target is therefore considered to be acceptable by the contractor. Again, however, recommendations concerning the requirements of high-resolution targets are given in Section IV of this report.

11. TKC 12 - Astigmatism and Orthogonality Target: The astigmatism and orthogonality target contains 29 crossline elements positioned as shown in Figure 6.

Acceptance tests were performed on this target to determine the accuracy of the crossline positions using a David W. Mann Comparator with a measurement accuracy of ± 1 micrometer.

The results of these tests are given in Table VI. The actual (measured) crossline positions are compared to the specified positions. As indicated, the maximum error is found to be 4 micrometers. Therefore, the actual target tolerance is ± 4 micrometers, which is within the 0.0002-inch (approximately ± 5 -micrometer) accuracy specified.

Based upon this measured error in crossline position, the accuracy of the target can be determined in terms of orthogonality. The orthogonality can be defined in terms of the X and Y positioned errors as follows:

$$\theta_o = \tan^{-1} \Delta X / \Delta Y$$

where θ_o = orthogonality error in seconds of arc,

ΔX = X crossline position error for selected crossline,

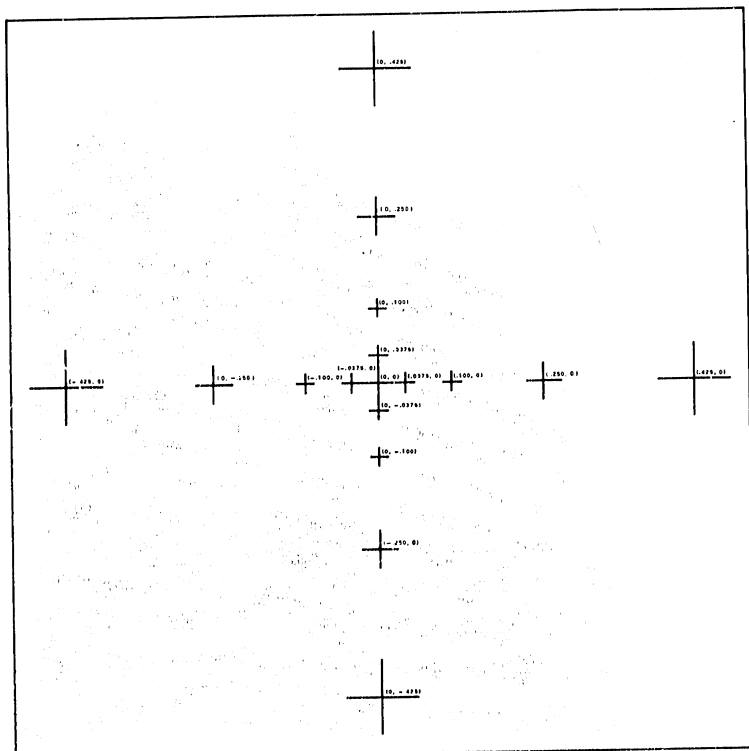
ΔY = actual Y crossline position, since target is centered at $Y = 0$.

Therefore, for the maximum Y crossline position (coordinates 0, 44.450 millimeters), the maximum error in X position relates to an orthogonality error of

$$\begin{aligned}\theta_o &= \tan^{-1} \Delta X / \Delta Y \\ \theta_o &= \tan^{-1} 4 / 44.450 \\ \theta_o &= 18.56 \text{ seconds of arc}\end{aligned}$$

This is within the proposed orthogonality accuracy of 0.5 minute of arc.

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(x, y) COORDINATES ARE GIVEN IN THE DRAWING FOR REFERENCE ONLY AND ARE NOT TO BE PRINTED ON THE TARGET PLATE.

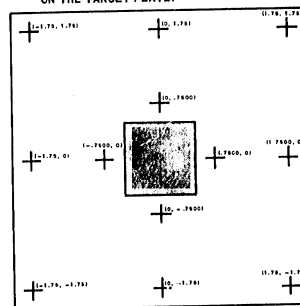


PLATE DIMENSIONS: 4.0" x 4.0"

1" x 1" GRAY AREA ABOVE ENLARGED TO 10X AT LEFT

± .0002" POSITIONAL ACCURACY AT EACH CROSS POINT
 .0002" LINE WIDTH THROUGHOUT

Figure 6. Astigmatism and Orthogonality Target

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12. TKC 13 — Transparent Scale: The transparent scale is 5.0 millimeters in length and has a specified precision of 0.01 millimeter. A microdensitometer scan of the scale yielded an accumulative error across the 5.0-millimeter length of less than 3 micrometers. The maximum error for a single line position was found to be less than 3 micrometers.

The test results indicate that the target meets all specifications. The microdensitometer analog data charts are not included in this report due to their overall length. However, they are available to the sponsor upon request.

13. TKC 15 — Stage Micrometer: The stage micrometer scale is 2.0 millimeters in length and has a specified precision of 0.01 millimeter. A microdensitometer scan of the scale yielded an accumulative error across the 2.0-millimeter length of less than 3 micrometers. The maximum error for the 0.1-millimeter division lines was found to be 3 micrometers.

The test results indicate that the target meets all specifications. The microdensitometer analog data charts are not included in this report due to their overall length. They are available to the sponsor upon request.

14. TKC 16 — Metal Scale: This component is a satin-chrome, spring-tempered metal scale 50 centimeters in length with four separate scales and precisions as listed below.

Scale	Precision
50 millimeter	0.5 mm
50 millimeter	1.0 mm
10-1/8 inch	1/32 inch
10-1/2 inch	1/64 inch

The accuracy of this scale was tested using a height gage and calibrated block gage blocks. The results of this test are listed in Table VII. A review of these results indicates that the maximum error found on the 1/64-inch scale is 0.001 inch. The maximum error on the 1/2-millimeter scale is 0.01 millimeter. Therefore, the scale meets all specifications, as indicated by the test results, and is acceptable to the contractor.

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TABLE VII. MEASUREMENT DATA FOR 50-cm METAL SCALE

<u>1/64-inch Scale Reading (inches)</u>	<u>Block Values</u>	<u>1/2-mm Scale Reading (mm)</u>	<u>Block Values</u>
1	0.000 Start	10	0.00 Start
2	1.000	100	99.99
3	1.999	200	200.00
4	2.999	300	300.00
5	4.000	400	400.00
6	5.000		
7	6.000		
8	7.000		
9	7.999		
10	—		
11	10.000		
12	—		
13	12.000		
14	—		
15	14.001		
16	15.001		
17	16.000		

15. TKC 19 - Vernier Callipers: The vernier callipers are made of hardened stainless steel with two chrome-plated scales. One scale has 16-millimeter length with a precision of 1/20 millimeter. The other scale has a 6-1/2-inch length with a precision of 0.001 inch.

Acceptance tests were performed on the inch scale to determine its accuracy at 13 randomly selected increments. Again, Hoke gage blocks were used as the standard of measure. The maximum error found was less than 0.001 inch, as read visually. Therefore, the vernier callipers meet all specifications and are acceptable to the contractor.

16. TKC 20 - Dial Indicator: The dial indicator has a range of 0.2 inch with a precision of 0.001 inch. Acceptance tests were performed to determine the accuracy of the indicator values, using calibrated Hoke gage blocks and a flat surface plate.

The results of these tests are given in Table VIII. The maximum error was found to be 0.0009 inch, which is within the specified tolerance of the dial indicator. The dial indicator is acceptable to the contractor.

TABLE VIII. MEASUREMENT DATA FOR DIAL INDICATOR

<u>Block Values</u>	<u>Dial Indicator Reading</u>
0	0
0.1000	0.0997
0.1500	0.1491
0.1100	0.1098
0.1200	0.1200
0.1300	0.1300
0.1400	0.1396
0.1050	0.1051
0.1150	0.1150
0.1600	0.1592
0.1750	0.1744
0.1900	0.1903

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17. TKC 24 — Stop Watch: The stop watch has a time capacity of 30 minutes and a precision of 1/10 second. The acceptance test utilized for the stop watch consisted of a time comparison against the National Bureau of Standards radio station WWV. Six time checks were made and the maximum error was found to be 0.2 second. This error included both the watch error and the human reflex error for times of one-minute duration. The watch is considered to be acceptable by the contractor since the reflex error is significant.

18. TKC 25 — Light Meter: The light meter is a standard Weston Master V Universal Exposure Meter. Its purpose is to indicate general light levels rather than make precision illumination measurements. Therefore, its ability to be calibrated against a standard source and provide repeatable readings is of greater importance than watching the general conversion specifications of the manufacturer.

The acceptance test program was designed to determine these factors using a calibrated tungsten-halogen 1000-watt lamp which is traceable to the National Bureau of Standards. The color temperature of the lamp is 3200°K, and the calculated meter-candle equivalents are based upon known illumination values of a diffuse white surface placed at a given distance from the calibrated source.

The results of this test program are shown in Table IX. As indicated from these results, the position in which the meter is placed during the measurement significantly affects the meter reading. However, the importance of this difference in reading due to position cannot be established at this time. First, the intended use of the meter specifies that it will always be in the horizontal position. Second, the calibration values apply only to the contractor's source and test setup, whereas the intended use specifies that the meter be calibrated against a standard light meter owned by the sponsor and located in the sponsor's testing facilities. Therefore, the different position values given are intended to emphasize to the sponsor the importance of utilizing the meter as described in the Optical Test Kit Procedures Manual rather than to test its accuracy.

The values given within the horizontal position columns of Table IX were found to be repeatable and can be used to calibrate to the contractor's test setup. Based upon this result, the meter is acceptable to the contractor. However, further recommendations regarding its use will be given in Section IV of this report.

TABLE IX. MEASUREMENT DATA FOR WESTON MASTER V METER
(Model 748, Serial No. 282PN)

Meter Readings	Values in Meter-candles Per Different Meter Positions				
	Weston Standard	Low End of Scale Down	High End of Scale Down	Meter Vertical Scale Up	Meter Horizontal
13	800	1037	1014		
12.5	580	683	634	891	
12.0	400	456	414	587	726
11.5	290	300	263	388	462
11.0	200	205	170	261	302
10.5	144	144	109	183	206
10.0	100	117	102	123	140
9.5	72	68	66	79	89
9.0	52	46	45	56	61
8.5	36	31	31	40	40
8.0	26	22	26	26	29
7.5					

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19. TKC 31 — Step Tablet: The step tablet contains 21 steps with a density range from 0.5 to 3.00 in density increments of 0.15 ± 0.03 . Density measurements were taken using a Macbeth TD-102 densitometer to determine the accuracy of the density steps.

The results of the density measurements are given in Table X. The maximum density error is 0.03, which meets the specifications of the manufacturer.

B. CLASS II INSPECTION

An outline of the methods and results of the Class II inspection is given in Table XI. Each of the component tests is described in the following discussion, using the TKC numbers as the component reference.

1. TKC 8 — Large-Field Grids: Two sets of large-field grids are included in the test kit. The two sets are identical in grid formats, but one has a 9 x 9-inch area and the other has a 4 x 5-inch area. The accuracy of the grid formats was measured using the previously tested 50-centimeter scale (TKC-16).

For the 9 x 9-inch grids, the maximum line-spacing error in one direction was 0.005 inch, while the maximum line-spacing error perpendicular to this was 0.006 inch. For the 4 x 5-inch grids, the maximum line-spacing error in one direction was 0.003 inch, while the maximum line-spacing error perpendicular to this was 0.003 inch. In every case, the measured error is less than the specified precision of 0.1 inch and 0.2 inch, for each of the grids.

2. TKC 14 — Translucent Scale: The translucent scale consists of a plastic tape scale in firm contact with a glass slide. The scale provides acceptable precision for large area measurements at very low cost.

The scale has a 19-centimeter length with a precision of 2.0 millimeters. Acceptance tests were performed to measure the accuracy of this scale, using the 50-cm metal scale (TKC-16). Comparison of the scales indicated a maximum error of $1/5$ of a division on the translucent scale over a length of 15 centimeters. This corresponds to an error of 0.04 millimeter, which is within the specified 2.0 millimeter precision.

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TABLE X. MEASUREMENT DATA FOR STEP TABLET

<u>Step Number</u>	<u>Specified Density</u>	<u>Measured Density</u>
1	0.05	0.05
2	0.20	0.21
3	0.35	0.37
4	0.50	0.51
5	0.65	0.67
6	0.80	0.83
7	0.95	0.97
8	1.10	1.11
9	1.25	1.25
10	1.40	1.40
11	1.55	1.54
12	1.70	1.69
13	1.85	1.83
14	2.00	1.99
15	2.15	2.13
16	2.30	2.27
17	2.45	2.42
18	2.60	2.57
19	2.75	2.74
20	2.90	2.91
21	3.05	3.06

TABLE XI. CLASS II INSPECTION OUTLINE

<u>TKC</u>	<u>Component Description</u>	<u>Method of Inspection</u>	<u>Precision</u>
8	Large-Field Grids	Against 50-cm Scale	0.1 in. 0.2 in.
14	Translucent Scale	Against 50-cm Scale	2.0 mm
17	15-cm Scale	Against 50-cm Scale	1/2 and 1 mm 1/64 and 1/32 in.
18	Measuring Taps	Against 50-cm Scale	1/16 in.
21	Surface Thermometer	Laboratory Thermometer	2°F
22	Tension Tester	Laboratory Weights	2 oz

3. TKC 17 — Machinist Scale: This component is a satin-chrome, spring-tempered metal scale 15 centimeters in length with four separate scales and precision as listed below.

<u>Scale</u>	<u>Precision</u>
15 centimeter	0.5 mm
15 centimeter	1.0 mm
6 inch	1/32 inch
6 inch	1/64 inch

The accuracy of this scale was tested using the 50-centimeter metal scale (TKC-16). Measurement errors could not be observed even under a 5X magnification. The 15-centimeter scale accuracy is accepted as having the same accuracy as that listed for the 50-centimeter scale given in Table VII.

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4. TKC 18 — Tape Measure: A 6-foot retractable tape measure with a precision of 1/16 inch is provided in the test kit. The accuracy of the tape was tested against the 50-cm metal scale (TKC-16), and no visible errors were observed. Again, the accuracy is accepted as equivalent to that of the 50-cm scale given in Table VII.

5. TKC 21 — Surface Temperature Thermometer: The surface temperature thermometer is a circular disk of 2-inch diameter with a temperature measurement range of 0 to 300°F and a precision of 2°F.

The surface temperature thermometer was tested against several laboratory thermometers used by the contractor in a laboratory facility. The results of the tests indicated a maximum error of 2°F at ambient temperature. This was considered acceptable by the contractor.

6. TKC 22 — Tension Tester: The tension tester was included in the test kit upon request of the sponsor for the purpose of measuring film tension. It has a 12-pound spring scale with a precision of 2 ounces and a 6-kilogram scale with a precision of 0.05 kilogram.

The accuracy of the tension tester was measured using standard laboratory weights which were randomly selected. The maximum error was determined to be 1/2 of the smallest kilogram division, which corresponds to approximately 0.03 kilogram or less than 2 ounces. The accuracy of the tension tester is acceptable to the contractor.

C. CLASS III INSPECTION

All test kit components inspected under Class III inspection procedures were found to be acceptable. This included all components listed in Table XII. The outline given in this table is self-explanatory and the components listed are readily recognizable, so that a detailed description will not be given.

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TABLE XII. CLASS III INSPECTION OUTLINE

<u>TKC</u>	<u>Component Description</u>	<u>Method of Inspection</u>	<u>Accuracy</u>	<u>Precision</u>
23	Hole Punch	Visual	N/A	—
26	Illuminator	Visual	N/A	—
27	Variable Angle Reflector	Visual	N/A	—
28	Polarizing Filter	Visual	Close to $\approx 2\%$	—
29	Spectral Filters	Visual	N/A	—
30	Neutral Density Filters	Visual	± 0.05	—
32	Lens Brush	Visual	N/A	—
33	Hand Magnifier	Visual	2X	—
34	Flashlight	Visual	N/A	—
35	Case	Visual and Fit	N/A	—
36	Glass Plates	Visual	—	—

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SECTION IV

SUMMARY AND RECOMMENDATIONS

The components included in the optical equipment test kit were selected to meet the sponsor's acceptance testing requirements for large optical systems and to provide this capability at a reasonable cost to the sponsor.

Throughout the development program, the contractor and the sponsor's technical representatives have conferred on the selection of the components, the testing procedure requirements, and the preliminary acceptance testing procedures that were performed by the contractor. In addition, several meetings were held to review the program status, including preliminary acceptance tests performed by the sponsor's technical representatives at the contractor's facilities.

In conclusion, the final phase of this program required the contractor to deliver the following items, in addition to this report, to the sponsor's technical representatives:

1. Optical equipment test kit, and
2. Optical equipment test kit procedures manual.

Subsequent to this program, the sponsor's technical representatives will have to evaluate the ability of the test kit components and the procedures manual to meet their acceptance testing requirements. During the period of this evaluation, it is recommended that the sponsor's technical representatives give particular attention to the following items.

1. High-Resolution Targets: The two targets included in the test kit were found to have a considerable change in contrast between group 4 and group 9, 16 line pairs per millimeter through 912 line pairs per millimeter. Although they meet the manufacturer's specifications, as shown by the microdensitometer results, and are visually acceptable, they do not meet the high- and low-contrast specifications of Mil-Std-150A over their entire resolution range.

Based upon these results, it is recommended that the sponsor initiate a high-resolution target development program, either internally or externally, to include:

- a. Evaluation of the applicability of the high- and low-contrast specifications, as given in MIL-Std-150A, to the resolution requirements of high-power optical instruments;
- b. Establishment of the acceptable contrast requirements for high- and low-contrast targets — specifically, the acceptable tolerance for contrast changes over the entire range of the target;
- c. The initial development of a prototype target that meets these contrast specifications. If performed externally, this may require a contractual agreement for acceptance of the best effort on the part of the contractor.

2. Orthogonality Target: The development of this target was based on fulfilling orthogonality accuracy requirements of 30 seconds of arc. The target included in the test kit meets these requirements. However, it may be possible to develop an orthogonality target, based upon the source method used in the development of this target, with a higher accuracy in terms of fewer seconds of arc. However, this type of target would be recommended for use in laboratory facilities rather than for field testing.

3. Illumination Meter: The Weston Master V Universal Exposure Meter must be used in strict conformance to the operational procedures outlined in the test kit manual. In addition, it must be calibrated by the sponsor's technical representatives to the standard meter owned and operated by the sponsor. If the meter calibration requirement cannot be fulfilled, it is recommended that another type of meter be utilized in subsequent test kits. The meter included in this kit was selected in an attempt to fulfill dimensional requirements of the test kit at a reasonable cost to the sponsor. Other types of meters with higher accuracy are available but at a much higher cost.

4. Prototype Package: Throughout the development of the optical equipment test kit, every effort was made to minimize the dimensional size of the kit to provide maximum portability. The goal was to design a package that could accompany the sponsor's technical representatives aboard an airplane and fit under a standard airline passenger seat. However, the amount and size of the equipment presently included in the kit does

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not allow for this maximum portability goal to be realistic. The present size of the kit is approximately twice the size required for maximum portability.

Therefore, it is recommended that the sponsor's technical representatives establish an equipment priority list that can be utilized in the development of future kits if a reduction in the test kit size is required.

5. Diopter Telescope: The test results of the diopter telescope, given in Section III of this report, indicate that its depth-of-focus may not be satisfactory for use in the measurement of focus position for high-power optical systems. If the sponsor's technical representatives require future focus position measurements, such as in a development program for the measurement of astigmatism, distortion, or chromatic aberration, it will be necessary to include in the program: (1) An evaluation of the focus measurement capabilities of present diopter telescopes on the sponsor's optical viewing systems, and (2) consideration toward the possible design requirements and development of a diopter telescope that would meet focus measurement specifications for the measurement of optical aberrations.